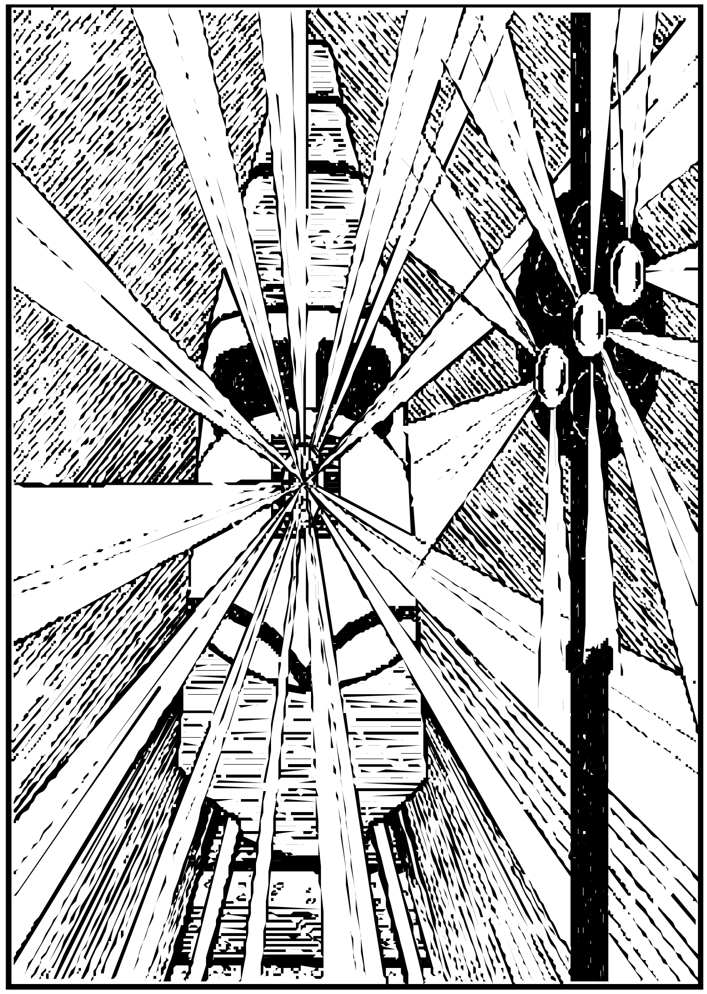
Attachment 3

Wireless for Railroads



The primary operating practices of freight railroads have changed little in nearly a century given the dependence upon traditional technologies. Now with the availability of wireless data networks in concert with advanced management systems, railroads can make a paradigm shift in their processes to optimize the efficiency of their extensive key operating resources including track time, locomotives, yards, and crews. Additionally, the expanded use of wireless technologies can support the tighter integration of operations between freight and passenger railroads, other transport modes, and public safety.

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* Railroad-ese when first used in this document is in *italics* and defined either in the text or the Glossary

Wireless for Railroads

PURPOSE

This paper addresses the extraordinary opportunities railroads have, both individually and collectively as an industry, to advance their operations via the use of advanced wireless technologies, as well as to improve the efficiency of their spectrum usage. This perspective is expanded to consider the relationship of the freight rail industry with passenger rail, other transportation modes, and the intersection with public safety. This is a **STRATEGIC PERSPECTIVE** based upon identifying both the **DEMAND** for and **SUPPLY** of wireless technologies which provides the basis for structuring an approach for **MOVING FORWARD.**

BACKGROUND

Since the 1st and 2nd quarter of the last century, North American railroads have depended upon two primary technology platforms for managing the safe movement of their trains, i.e. *signaling traffic control systems* (a railroad's traffic lights) and analog wireless voice communications respectively. As such, the railroads have been constrained as to the level of efficiency of traffic movements that they can achieve due to the use of traditional management processes based upon the two technology platforms. However, the tremendous increase in rail traffic over the past decade, especially with the advancement of *intermodal* operations, is pressing the railroads to provide additional capacity, for which they have two primary alternatives. That is, they can take the traditional approach of making substantial investment in additional track infrastructure and related resources, and/or, as will be addressed in this document, they can use wireless data networks and management systems to significantly improve both the safety and efficiency of their operations, thereby minimizing the capital investment for additional resources.

Given both the traditional processes of railroads as well as the substantial investment in analog wireless infrastructure, the railroads have been reluctant overall to a take on revolutionary changes to operating practices. It has only been within the last several years that two *Class I* railroads in particular have incorporated advanced traffic planning tools into the dispatching operation, an improvement that is primarily due to the availability of wireless data networks, both commercial and private. Simply stated, wireless data networks offer the railroads the opportunity to make a major paradigm shift in managing their key operational resources in a *proactive* fashion [1]. The underlying logic is straightforward.

- The more timely the status of assets are known (to a point), then the better the assets can be managed.
- And since a railroad's primary assets are mobile, then wireless data systems are required to obtain those timely data.

While each railroad could advance a wireless data platform for its individual use, and several have, there is also an industry perspective given the substantial interchange of trains between railroads. Similarly, there has been relatively little consideration by the freight railroads as to the use of wireless relative to their interactions with other transport modes as well as with public safety.

Given the above, the railroads could benefit from a comprehensive understanding of what can be done (DEMAND) with wireless data networks given both current and advancing wireless technologies (SUPPLY). One methodology to do so will be addressed in this report in **MOVING FORWARD**.

DEMAND [1]

Railroads have used wireless, radio frequencies (RF), for communications since the 2nd Qtr of the last century. Initially, wireless networks were set up along a railroad's main tracks, a.k.a. *main line,* for voice communications so as to eliminate the *dispatcher* telephone line mounted on *pole lines.* This permitted a train crew to talk to dispatchers to receive *movement authorities* to advance the train without stopping the train to use a wayside telephone. As such, the use of wireless along the main line requires only a few channels in any given geographical area to handle a low level of voice communications. Additionally, wireless voice became the chief means to coordinate activities within and between crews within railroad yards. However, unlike main line operations, each yard crew is assigned a dedicated channel for safety purposes. Therefore, with a heavy congestion of trains and yards in major metropolitan areas, the coordination between railroads of less than 100 channels in the 160-162 MHz band licensed to railroads has been an extremely difficult balancing act. This latter situation has given many the impression that the band is heavy congested across the industry, which in fact it really isn't especially if proper technologies were used, as addressed 1
later. In either situation, main line or yard usage, the effective use of the 160-162 MHz band spectrum in terms of transmission versus available time continues to be quite low given the lack of significant wireless voice traffic across the railroad overall.

It has only been in the last two decades that wireless data has been used by railroads for communication between devices to complement the voice communications for personnel. In general, such efforts to date have loosely been referred to as *Intelligent Railroad Systems*, with most being pursued on an individual railroad basis without any coordination across the industry. The first such use across the industry was that of end-of-train (EOT), a radio telemetry solution in the 450 MHz band that was initially used to permit the engineer (train operator) to monitor the *brake line* air pressure at the end of the train, thereby eliminating the requirement for cabooses. Subsequently, EOT was expanded to permit the engineer in the locomotive to release the air pressure at the end of the train in addition to the release from the locomotive for more uniform emergency braking.

Following EOT, railroads have utilized wireless data networks, both private (220, 450, & 900 MHz bands) and commercial, for singular applications such as monitoring locomotive diagnostics, downloading data from the locomotive's event recorder (a locomotive's black box), remotely controlling locomotives (*RCL*) in a yard, and replacing the *code line* on the pole line so as to eliminate the need for such infrastructure subject to extreme weather such as tornadoes and ice storms. One of the results of the deployment of singular wireless-based applications over the years is a complex wireless environment on board the locomotive that may have up to 14 antennas on its roof to handle the variety 2
of wireless-based applications. Such a configuration is evidence of duplicate RF coverage due to individual departments within a railroad pursuing their individual applications with individual wireless paths.

With the intent of breaking away from the singular problem / singular solution approach to implementing wireless-based applications, two significant efforts have been performed in

[1] Callouts are used in this segment to note the highlights shown at the end of **DEMAND**

the past 15 years to define the opportunity for improving the use of wireless spectrum and technologies by freight railroads. The first effort in 1996, coordinated by the *American Association of Railroads* (*AAR*) and facilitated by IBM, was a review of the primary operating processes used by a railroad and determining whether or not wireless could be of benefit. A year later this study was expanded in context by IBM by applying *Business System Planning (BSP)* techniques to define an information flow architecture within a generic railroad. Dubbed the **Demand Study**, the AAR was able to use this report in its subsequent discussions with the Federal Communications Commission (FCC) in justifying the industry's RF requirements at that time[2].

The second effort to define the opportunity for wireless was a study that was performed 3 years ago. Sponsored by the Federal Railroad Administration (FRA), this study was more strategic and functional than structural as with the 1996 study. Titled "An Analysis of the Opportunities for Wireless Technologies in Passenger and Freight Rail Operations", the study involved railroads and suppliers alike, both individually and collectively, in a series of interviews and work sessions to identify and describe specific advancements in freight rail operations that could be made with wireless technologies [3]. As informative as the study was in identifying and describing the opportunities for wireless, it also expanded the boundaries of operability, theretofore viewed only as *railroad interoperability*, i.e., the ability of a train to cross railroad boundaries without a loss in functionality. Understanding additional levels of operability is critical not only as to improving the capability of the rail industry overall, but also in defining the type of wireless technologies and spectrum that can be used. Hence, the remainder of this DEMAND section highlights both the **Opportunities** to advance rail operations via wireless as well as describe the various levels of **Operability**.

Opportunities

The opportunities for advancing rail operations via wireless systems can be viewed as to 5 primary objectives: 1. Increase traffic velocity, 2. Optimize resource utilization, 3. Minimize maintenance costs, 4. Improve customer service, and 5. Ensure safety. Each of these is discussed below as to their respective opportunities.

Increase Traffic Velocity: Arguably, the most important objective for a Class I railroad currently is that of *traffic velocity*, i.e., the average rate of travel for trains across a railroad's infrastructure. The greater the velocity, then the greater the capacity that the railroad can handle with its given infrastructure, thereby offsetting or minimizing the investment in additional infrastructure. However, the railroads are now finding themselves constrained with their traditional technologies and associated operations processes to make any additional significant increases in velocity with their current infrastructure. To a great extent this is due to the fact that freight railroads effectively operate in a non-scheduled fashion given the continuous occurrence of conflicts in train movements. Such a *reactive traffic management* environment can be quite challenging in considering the number of parameters that are involved in coordinating train movements, including yard availability, train crew work limits, fueling, and opposing trains on single tracks.

With the use of wireless data networks, timely and accurate train speed and position data can be obtained and fed to mathematical planners that can optimize the performance of such parameters. That is, railroads can make the transition from reactive traffic management to *proactive traffic management* (PTM) where forthcoming conflicts are projected by means of *mathematical planers* with solutions being provided to the *dispatcher* to minimize consequences, if not avoid the conflicts altogether [1]. What is most interesting is that such a transition can be made with relatively little investment and delay. Specifically, the reporting frequency of position and speed data required to use the mathematical planners adequately is no more frequent than every 5 minutes, thereby negating the need for a sophisticated wireless network. Additionally, the mathematical planners can be provided without modifying or replacing a 5 railroad's current computer assisted dispatching (*CAD*) platform.

It should be noted that the value of PTM operations diminishes as a railroad increases its degree of 6 truly scheduled operation. However, given the substantial interchange of trains between railroads, the ability to run to a true schedule for any one railroad relative to that type of traffic is subject to the schedule efficiencies of the roads with which it interchanges. Unlike the passenger airlines that can operate to schedule without concern about other airlines, running a truly scheduled railroad operation requires the appropriate management mindset and commitment from across the industry. Without such a commitment, PTM offers the best opportunity for an individual railroad to optimize its performance.

Optimize Resource Utilization: While track time can be best managed via PTM, as measured by traffic velocity, there are other primary resources that can be better managed with availability of more timely status data as well. The most important assets across the industry are train crews, locomotives, yard availability, critical rolling stock, and fuel. However, the efficient management of all of these is dependent upon the efficiency of train movements, and the more unscheduled the trains are, the greater the inefficiency of the resources. Specifically, in unscheduled operations where temporary, local shortages occur due the lack of predictability of where resources will be at 7 any given time, a railroad compensates by deploying excess (*slack*) resources to ensure that trains can operate. Such *unstructured* inefficiencies can be significantly high. Even in truly scheduled operations, extra resources are deployed as well. However, these *structured* inefficiencies are less costly, more efficient, then the unstructured inefficiencies of non-scheduled operations.

Minimize Maintenance Costs: Much of a railroad's critical infrastructure and equipment is subjected to strict regulatory maintenance practices developed and enforced by the Federal Railroad Administration (FRA), including grade crossing systems, locomotives, and signaling infrastructure. With the advancement of electronics, the operation of many of these remote or mobile equipment and systems has become increasingly reliable. However, to a great extent they are still subject to *prescriptive* practices that outline temporal parameters for inspections and repairs regardless of the actual condition of the equipment and components. Such inspection requirements are extremely costly and too often unnecessary except for the practice of it being better to be safe than sorry. With the use 8 of wireless technologies, there is the opportunity to move to *performance-based* maintenance where remote or mobile equipment and components can be monitored as to their operational status with sufficient accuracy and predictability to initiate maintenance activity only when actually required. Additionally, with the availability of nationwide wireless coverage, then such performance-based maintenance can be provided for equipment regardless of where it is operating, most importantly the significant number of locomotives that operate over multiple railroads across the continent.

Improve Customer Service: In addition to the improvements in customer service that will result from railroads operating more efficiently 9 and reliably as to schedule, shippers can benefit directly from the use of wireless. Specifically, wireless can provide for direct monitoring of shipments by shippers regardless of the railroad over which the cargo is traveling. Additionally, if permitted by the railroad, shippers can be in direct communications with train crews that are dropping off or picking up rail cars on an immediate basis, thereby avoiding the delays involved with traditional work order processes.

Ensure Safety: Ensuring the safety of the railroad has a wide spectrum of meaning, not the least of which is protecting employees, preventing train accidents, safe handling of hazardous material, and being proactive as to preventing possible terrorist activities. Wireless has, and continues to play an increasingly important role in these areas [4]. Examples follow:

- As noted earlier, railroads use traffic control systems to ensure the safe movement of trains. The two primary types of traffic control used by freight railroads, i.e., signaling and *non-signaling*, can benefit by the use of wireless data to improve both their availability and their efficiency of operations.

- In 2008 the Federal government mandated the deployment of enforcement system, generally referred to as *Positive Train Control* (PTC), before 2016 for most of the freight and passenger rail operations across the U.S. Via the use of wireless data and GPS positioning, PTC prevents train accidents due to operator errors. While the cost of implementing PTC relative to its value over the next 20 years is projected to be a ratio of 20 / 1 [11], the wireless data infrastructure being deployed could be used for other business applications, e.g. PTM. Additionally, PTC has the possibility of being used to balance the perceived or real safety issues with other changes in operating practices that can provide substantial business value, e.g., reduction to one-man crews. It should be noted that there are two primary types of PTC approaches that are significantly different from each other. One will be used by the freight railroads, and the other, *ACSES*, will be used by Amtrak on the Northeast corridor (NEC)

- Wireless data networks provide for the monitoring of critical shipments for domestic security purposes as to detecting tampering, tracking chain-of-custody, and providing timely location data. Additionally, wireless data networks are used for monitoring remote locations and critical structures as to security status and operating status.

- Wireless data networks provide connectivity for wayside sensing devices along the railroads' mainlines that are used to measure and report critical parameters of rolling stock, e.g., hot box heat detectors, dragging equipment, excessive shipment height, etc., thereby permitting the prevention of derailments and other dangerous occurrences.

Operability

Operability can be generally defined as the ability to operate in a desired fashion in a cost-effective fashion in various environments. Until the last decade, railroad operability was limited to ***intra****operability*. That is, the engineering forces of the railroads were tasked with ensuring that whatever changes they made as to equipment, infrastructure, systems, and procedures could be handled across their specific railroad without undue consequences in performance or costs. Due to a Federal Communications Commission (FCC) rulemaking as to *narrowbanding* VHF, including the 160-162 MHz band used by railroads, the Class I railroads began addressing *railroad* ***inter****operability* (again, trains crossing railroad borders) from a wireless standpoint within the last decade. However, it wasn't until the Federal PTC mandate in 2008, that the Class I railroads took upon themselves to develop both technical and functional solutions to provide for the interoperability of PTC. Recognizing the complexity of the effort, it is not surprising that they have not considered the wireless requirements for interoperability on a broader business and boundary basis [5].

However, there are considerable reasons to do so, and for several different levels as described below. 11

Industry INTRAoperability: With very few exceptions, railroad's have limited their use of technologies and the management of their mobile assets to their own property. Yet, there are valuable benefits to be achieved by providing for an *industry* ***intra****operability* perspective, i.e., being able to track the status of mobile assets across the industry regardless of the property over which they are operating. Examples follow:

- Maintaining a thorough chain of custody for critical shipments;
- Knowing the operating condition of a *foreign locomotive* in the train;
- Knowing the fuel level of locomotives at interchange points;
- Being alerted as to the health of critical shipments throughout the trip;
- Having an accurate ETA for foreign trains approaching interchange;
- Permitting performance-based maintenance of locomotives in lieu of the current prescriptive based; and
- Establishing an industry-wide approach for locomotive maintenance and part warranty.

Cross industry operability: This level of operability brings the railroads in contact with other transportation modes as well as shippers. Consideration of such interaction started primarily with the initialization of *Intelligent Transportation Systems* (ITS) established by the Intermodal Surface Transportation Efficiency Act of 1991 12 (ISTEA). The importance of such interconnection was expanded as the result of 9/11 relative to domestic security, and more recently with the mandate of PTC in 2008 which requires interoperability between freight and passenger rail operations. This level of operability has the greatest challenges as to defining functionality, using spectrum, and applying technologies, and as such will be addressed below in **MOVING FORWARD**.

Train INTRAoperability: What has yet to be fully appreciated, yet alone developed, are the requirements for communications within a train. As noted earlier, EOT was the first use of wireless data across the industry which provided the telemetry of information between the locomotive and the end of the train. Since then, *distributed power* has been used in select situations where locomotives are positioned mid-train to provide additional power in sync with the locomotives at the head of the train. Additionally, there are valuable opportunities for communicating between rail cars, shipments, and the locomotive as to conditions that might affect the health or safety of the operation.

Callouts: The following are summary points regarding the demand of wireless by the railroads as noted by call outs above.

1. The effective use of the railroad's160-162 MHz band is quite low.
2. The singular pursuit of wireless applications has resulted in duplicate RF paths.
3. Railroad interoperability is the only level of operability being actively pursued.
4. PTM requires relatively little wireless data.
5. PTM does not require a new CAD platform.
6. Railroads are generally unscheduled.
7. Railroads employ excessive slack resources due to the lack of scheduled operations.
8. Wireless data offers the increased possibility for performance-based maintenance.
9. Wireless data offers new levels of customer service.
10. PTC is the impetus for the rail industry to actively pursue a wireless data network for the industry.
11. Industry intraoperability offers unique opportunities for advanced resource management that has yet to be recognized by railroads and suppliers.
12. BSP is one methodology for determining the opportunities to advance the use of wireless.

SUPPLY

As discussed above, the railroads have been using wireless for voice communications since the 1st half of the last century within the 160-162 MHz band. That band is subject to the FCC narrowband rulemaking that requires a substantial investment to replace the railroads' 250,000 radio units used in that band before 2013. Additionally the railroads have made substantial investments in two other bands, 450-460 MHz and 896-932 MHz, to support a few wireless data applications in the last two decades. All investments have been on an individual by individual railroad basis with frequencies coordinated via the AAR when necessary.

As to the replacement of the 160-162 MHz equipment, it should be noted that the railroads decided not to use technologies that could have substantially improved the poor efficiency of that band given the unique characteristics of its use along the mainline and in major metropolitan areas, as described earlier. Rather, several Class Is decided to acquire channels in the 220-222 MHz band to provide a new wireless data network in addition to the parallel 160-162 MHz network that could have supported substantial data and voice requirements if so equipped with proven technologies. Subsequently, with the PTC mandate, the Class Is elected to use the 220-222 MHz band for the first industry-wide network to provide interoperability. It should be noted that there was no regulatory requirement to use this or any other band for PTC. Aligned with this deployment, the major Class Is are designing their own high speed data radio platform.

In addition to the above wireless bands, one Class I railroad invested in a meteor burst platform that provides relatively inexpensive wireless data for both mobile to central office as well as peer-to-peer. That platform is now owned by the major Class Is, but without any known usage planned across the industry, at least at this point given the concerted effort to deploy the spectrum in the 220 MHz range for PTC.

With parallel networks along the mainline and various wireless networks elsewhere, including unlicensed WiFi, there are current and advancing technologies from which the railroads could benefit as to improving the spectrum efficiency of the various networks as well as minimizing the investment and maintenance costs of deploying unnecessarily-duplicate RF coverage. Additionally, in consideration of the various levels of operability described in **DEMAND**, there is also the consideration of interfacing with other spectrum bands, whether current or additional, to address the voice and data interactions between railroads, other transport modes, and public safety. The most noticeable, achievable technologies for these purposes are *trunked radio, software defined radio* (*SDR*), *cognitive radio* (*CR*), and commercial services as described below.

Trunked Radio: Since the late 1970's trunked radio systems, a.k.a. Specialized Mobile Radio (SMR), have been used to optimize the efficiency of particular RF bands to service the business community. Compared to conventional radio systems that require the user to choose a particular channel over which to communicate, SMR uses computers and a control channel to dynamically assign currently-available channels to users when requested. A simple analogy is that of having one queue in a bank in which a bank employee sends the next customer to any available teller, instead of having a queue for each teller and the customers having to wait an unpredictable amount of time to move to the head of the queue. Hence, the use of trunked radio technology would be extremely effective for the 160-162 MHz band in major metropolitan areas where there are many users, but with each having only relatively quick and few conversations.

As mentioned earlier, the railroads elected not to pursue trunked radio to meet the FCC narrow-band mandate. At that point a number of years ago, the railroads seemingly believed that the available analog trunked radio technology would be too difficult to configure. However, with the advancement of digital trunked radio, the railroads still elected to not pursue the possibility. Instead, they elected to obtain and build a parallel network in the 220 MHz range, thereby continuing the inefficient conventional radio structure for the new digital 160-162 MHz infrastructure.

Software Defined Radio: With the term SDR being introduced in 1991, it can most simply be described as replacing a number of hardware components of a radio unit with software. The underlying principle for doing so is the use of some form of digital signaling processors (DSPs) that can replace specifically designed hardware such as RF filters, mixers, amplifiers, and modulators/demodulators[6]. While that sounds interesting, the real advantage is that a single signal processing platform can instantly switch between an unlimited number of combinations of bands and protocols (a.k.a. multi-band, multi-function) provided the software is made available. From a railroad's standpoint that means that a SDR-based locomotive or base station radio can provide literally a wide spectrum of radio networks, networks that can be added as required on the same unit by incorporating the required software. Such a capability means that the challenges of supporting the various levels of operability defined in **DEMAND**, are more functional and political, then they are technical or financial – an important breakthrough in implementing advanced wireless technologies across the transportation industries.

Cognitive Radio: CR is the forthcoming advancement in the use of SDR. It can be simply defined as SDR with intelligence, i.e. artificial intelligence (AI). CR uses the multi-band, multi-function capability of SDR to dynamically meet the parameters of the users wireless requirements, including transmission power, geographical boundaries, and permitted users. The potential of CR for railroads is to expand upon the spectrum efficiency, data rates, link performance, and interoperability of SDR [7].

Commercial Services: Very few wireless-based applications for railroads are dependent upon real-time data transfer. Rather, most applications, including the most promising ones for advancing railroad operations, e.g., PTM, require relatively little data at relatively infrequent intervals with no consequences as to the safety of the operations. That demand consideration in concert with the nearly ubiquitous coverage of commercial services, whether satellite or terrestrial, suggests that railroads have the opportunity to quickly and inexpensively from a capital investment standpoint, deploy singular applications with commercial services. Unfortunately, it is not uncommon to hear both railroads and suppliers alike referring to PTC as the first step for advancing many business applications. However, that point is not true as has recently been demonstrated by one, if not two Class Is with their pursuit of PTM using wireless data other than that to be deployed eventually for PTC. This same point of not waiting for PTC can also be made as to pursuing the various levels of operability between railroads, other transport modes, and public safety.

The critical point of this section is that there are technologies, spectrum bands, and wireless platforms available that can be used to advance railroad operations now, with or without the advancement of PTC. Unlike PTC which has a greater cost than value, such advancements can greatly improve the railroads' bottom lines in the near future. However, few railroads individually, and certainly not as an industry, have developed a strategic perspective to make such advancements, as will be addressed in **MOVING FORWARD.** Rather, they have near-totally focused on meeting the PTC mandate.

STRATEGIC PERSPECTIVE

The railroads have an unprecedented opportunity to significantly advance their business practices given advancments in the last decade as to the *core technology infrastructure*, i.e., the combination of intelligence, positioning, & communications technologies. As noted earlier, traditional railroading processes have changed relatively little in nearly a century based upon the continued use of track circuits and voice radio. However, with distributed processing, advanced positioning technologies, and digital wireless technologies, railroads can make a paradigm shift in their operations by developing a stragegic operations perspective in sync with a strategic technology perspective, a.k.a. *Strategic Railroading*™[8]. This means performing pragmatic analyses of what the demands for technologies are and then balancing that demand against the supply of those technologies in a cost effective manner, including the likely possibility of making significant changes in primary operating processes.

In performing a strategic analysis of the use of wireless, it is necessary to take a *qualifying* approach instead of a *quantifying* approach as could be used for wired communications. That is, the degree of variation in the unique parameters of wireless, e.g., propagation, capacity, power, bandwidth, and access, prevents performing analyses with any degree of reasonable accuracy compared to wired networks. Therefore, the strategic approach presented below is one of identifying general categories of parameters for supply, demand, and value.

Beginning a strategic analysis requires recognizing several primary points:

- There are a seemingly endless number of combinations of technologies and spectrums that can be possibly used. However, each combination varies as to its throughput and coverage characteristics, as well as the cost to deploy;
- No one combination of technology and spectrum is likely to address all of the major requirements of railroads in the most cost effective fashion; and
- The railroads have a substantial investment in wireless infrastructure, albeit much of it requires further investment to meet the FCC's narrowband mandate.

The net of these three points is that a successful wireless strategy may be one that encompasses several sub-strategies based upon grouping together those demand requirements that have similar combinations of coverage and throughput. Subsequently, each sub-strategy can be explored as to the most cost-effective technology solution keeping in mind the opportunity to cost-effectively utilize current infrastructure. Hence, the following is one strategic approach for wireless deployment for railroads based upon developing a *Strategic Demand* perspective in sync with a *Strategic Supply* perspective.

Demand vs. Supply

As noted in **DEMAND**, there are both **Opportunities** and **Operability** perspectives of demand that need to be considered from a strategic demand versus supply perspective.

Opportunities: As should be expected, not all applications have equal value and nor do they have equal data throughput requirements of the wireless network. To address the two together is a critical consideration in the use of wireless technologies. Fortunately for railroads, as shown in Figure 1, one of the most valuable data requirements for wireless, PTM, is also one with the least data requirements. That is, being able to track each train along the main line as to its speed and position provides for PTM, the ability to increase schedule reliability, and the subsequent opportunity to better manage the key operating resources. Contrarily, the most demanding application for wireless, *moving block*, has substantially little value for some railroads, albeit significant value for others.

Figure 1

		VALUE		
		Low	Medium	High
DATA	Low	Remote Switch	Loco Mgmt Loco Maint Crew Mgmt	PTM Loco Fueling
	Medium	Domestic Security	Yard Mgmt *Mobile Node* Work Order	PTC Traffic Control *Flexible Block*
	High	Moving Block-East		Moving Block-West

Operability: While railroad INTERoperability has nearly the exclusive attention of railroads currently due to the PTC mandate, the other levels of operability identified in **DEMAND** offer tremendous value as well. However, they have yet to be given any serious consideration partially due to the lack of strategic perspective of how to deploy technologies in sync with a strategic perspective of operations. One way of addressing the various levels of operability for railroads, including the interaction with public safety and other transportation modes, is to consider the different types of geographical coverage required as well as the generic types of throughputs without regard to specific applications.

For railroads, coverage can be view as to 4 primary categories:

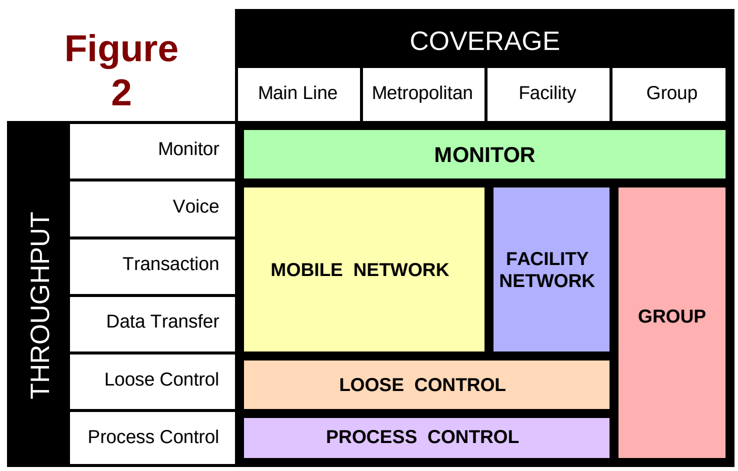
- **Main Line:** the inter-city traffic that includes most of a railroad's terrestrial expanse;
- **Metropolitan:** the major metropolitan areas that include multiple railroad facilities;
- **Facility:** an individual yard / facility;
- **Group:** a number of users that require communications between themselves when they are together and they may be disbursed at some time.

As to the type of throughput, wireless applications fall into 6 categories:

- **Monitor:** the transmission of remote data to a source of intelligence. The data flow is in-bound only;
- **Voice:** a two-way transmission that occurs randomly and may be of relatively long duration;
- **Transaction:** the interactive flow of data that is short in nature, but may occur quite frequently;
- **Data Transfer:** the two-way flow of considerable volumes of data that will occur with some predictability as to location or time of day;
- **Loose Control:** often referred to as *SCADA* in other industries, this two-way flow of data is associated with the remote control of equipment that is perhaps timely, but not critical.
- **Process Control:** the two-way flow of control data that is operationally and safety critical.

Matching the 4 coverage categories against the 6 throughput categories results in 24 different possible combinations of the two, and thereby suggesting a like number of individual technology solutions. However, based upon the two studies referenced in **DEMAND**, there are natural clusters of applications, as shown in Figure 2, that reduce the 24 different possibilities to 6 manageable *wireless corridors*., i.e., the deployment of a wireless network to handle a combination of wireless applications with similar coverage and throughput characteristics.

Figure 2



Monitor: A relatively low speed data rate corridor used primarily for inbound messages that may cover a railroad's total network including yards and main line. Applications that would be considered for this network are tracking high value, high security shipments, tracking and diagnostics of remote and mobile equipment, and status of wayside equipment and infrastructure.

Mobile Network: This network is used for both voice and data transmissions for personnel in the field, whether stationary or mobile. This network could replace the extensive use of commercial cellular by railroads.

Facility Network: This wireless corridor is used for voice and data transmissions in individual facilities, office campuses, or yard operations to replace the use of commercial cellular and possibly wired networks. Additionally, the wireless corridor would handle downloads to/from locomotives in support of PTC, event recorders, an on-board video.

Group: This wireless corridor may used for voice and data transmissions between personnel and/ or equipment. The individual network is only operational when the group, e.g., train consist or work gang, are active.

Loose Control: This wireless corridor is a *SCADA* platform that requires relatively low throughput, but reliable communications. Applications would include code line and remote equipment / infrastructure control.

Process Control: This is a very reliable, available wireless corridor with significant data throughput requirements. The primary application for railroads would be moving block operations.

The consideration of cross industry operability would likely expand the coverage / throughput categories shown in Figure 2 and identify additional and/or expanded wireless corridors. Once complete, the last step of the demand vs. supply analysis is to build technology strategies for each of the wireless corridors. Simply stated a successful wireless strategy is based upon a divide & conquer approach.

MOVING FORWARD

In general, railroads employ wireless technicians, but they don't employ wireless *technologists*, and the effect has been a loss in efficiency of key resources and investment in capital and maintenance costs for excessive infrastructure, including wireless. Unlike technicians, technologists blend a number of disciplines critical for the cost-effective deployment of technologies, including domain knowledge, operations research, finance, IT, and wireless [9]. Technologists are not Six Sigma warriors that are looking to minimize the cost of current processes. Rather, technologists are process engineers that make the business case to use technologies to advance operations in a cost effective fashion. Simply stated, that means pursing *revolutionary functionality* via *evolutionary deployment* of technologies where applicable. Examples of this theme that have been suggested in this report include

- Using commercial wireless services to report train position and speed data for use by a PTM platform until the network in the 220 MHz range is implemented;
- Incorporating PTM without replacing CAD;
- Expanding *RailInc's EMIS* (rolling stock repair data base service) to track locomotives / trains for providing ETA's for interchange;
- Expanding RailInc's EMIS to track locomotives diagnostics/repairs across the industry to support performance-based maintenance.
- Expanding critical tracking systems that exist in other transport modes, or via shippers, to track chain-of-custody as well as provide tracking of critical shipments for shipment and domestic security purposes;

- Implementing digital trunked radio in the rebuilding of the 160-162 MHz band, but only where truly needed, e.g., major metropolitan environments;
- Performing pragmatic data throughput analyses to determine the real demand across a railroad, across the industry, and in interaction with other transport modes and public safety.
- Developing a strategic information flow architecture for cross industry operability based upon the availability of wireless data networks.
- Viewing the locomotive as a *mobile node* on the railroad's IT architecture (as a manufacturer has fixed nodes), and establish the standards for the on-board computer platform for both PTC and business purposes using object oriented (O/O) architecture.

In the light of just the above examples, it is clear that railroads, both individually and collectively as an industry, have the opportunity to greatly improve their operations, reduce costs, and avoid unnecessary investment in excessive slack resources, including track, crews, locomotives, and wireless infrastructure. It is also clear that such advancements will not occur via the traditional management processes of being driven by middle management. As has been demonstrated by one Class I so far with PTM, the directive has to come from the top and be driven by a pragmatic process that ensures proper participation by all parties.

One approach to developing such a strategy is that which was mentioned earlier as to the use of the Business System Planning process (BSP). BSP is a very structured approach, developed by IBM in the 70's that identifies the generators, users, and modifiers of data associated with the business processes involved, whether they be current or identified by technologists. The resulting outcome of BSP is a well defined information flow architecture, including the identification of singular, unique data banks that serve as data clearing houses, if you will, and thereby avoid the duplication of data storage. With such an understanding, then wireless corridors, as defined earlier, can be identified with individual wireless strateiges involving both spectrum and technologies determined accordingly.

As to the point of spectrum specifically, it is understood that a nationwide PTC spectrum needs analysis is being conducted in conjunction with the Transporation Research Board (TRB). However, this is a relatively simple analysis compared to a much more complex set of issues that should be addressed, including the following:

- What are the true data requirements for PTC, both ACESS and the system being deployed by the freight railroads? And, do those requirements justify additional spectrum over that already obtained in the 220 MHz band by the railroads?

- What are the business applications that could be added to the on-board PTC platform, thereby expanding its functionality as an extension of a railroad's IT architecture? And, does such expansion justify spectrum in addition to that being used for PTC?

- What are the business applications associated with industry intraoperability and cross industry operability as noted earlier? And subsequently, what are the alternatives for spectrum to be so used, again in line with the wireless corridor approach?

In closing, to perform the strategic wireless analyses requires top level committment by rail management to provide the resources, i.e., the technologists, whether dedicated employees or contractors, to pursue a pragmatic approach. Additonally, given the influence on safety and efficiency, there is a vested interest by suppliers, passenger operations, regulators, and industry associations as well to participate in such analyses.

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AUTHOR INFORMATION

Ron Lindsey has 37 years in the rail industry both as rail management and as an consultant. As rail management Ron has held the positions of Chief Engineer Communications and Director Advanced Train Control for Class I railroads. In the later position he was the architect for the first overlay PTC system that provided the basis for the PTC pursuits by freight railroads to meet the PTC mandate. With 19 years as an independent consultant, meaning that he represents no suppliers nor accept commissions, he has performed a large number of assignments for the FRA, Class Is, and major suppliers directly aligned with the purpose of this document, including the following:

- Conceived and performed the referenced FRA-sponsored study regarding the use of wireless [3];
- Structured and participated in the referenced Demand Study [2];
- Structured and performeed a major BSP regarding the intermodal industry [10];
- Performed a strategic Crew Management Study for a Class I;
- Performed a tactical & strategic AEI Study for a Class I;
- Project leader to evaluate the safety and efficiency of the Egyptian National Railways;
- Performed market studies for suppliers in advanced track / catenary inspection systems, advanced grade crossing equipment, and RF progagtion tools;
- 15th year of publishing a quarterly journal, ***Full Spectrum***, with subscribers including Class Is, FRA, and major suppliers;
- Published in the *Journal of Transportation*, *IEEE Vehicular Technologies*, *Progressive Railroading*, and currently a Contributing Editor for *Railway Age*;
- Frequent speaker at rail conferences, both domestically and internationally;
- Teaches ***Railroad Immersion*** & ***PTC*** courses for railroads and suppliers to rethink technologies.
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GLOSSARY

AAR	Association of American Railroads: Industry association for the Class I railroads.
ACSES	Advanced Civil Speed Enforcement System used by Amtrak as a overlay PTC approach on their cab signaling operation in the Northeast corridor.
Brakeline	the pressurized air pipe that runs throughout the train to operate the brakes in a fail-safe manner. That is, pressurized air keeps the brakes apart from the wheels, and if that line is broken, then the brakes apply.
BSP	Business System Planning: A strategic process developed by IBM to structure an information flow / data bank architecture.
C A D	Computer Assisted Dispatching: the platform that permits the dispatcher to request routing for trains.
Class I Railroad	The largest railroads in the U.S. that exceed $250 million in operating revenues adjusted for inflation.
Code Line	the non-*vital* communication link between CAD and the wayside signaling infrastructure that permits the train dispatcher to make requests of the vital wayside infrastructure to route trains as well as provide indication of wayside signals - a *SCADA* platform.
Dispatcher	an operations individual that determines the routing of trains. Such decisions are protected from being in error via the use of *traffic control* systems.
Flexible Block	a near optimal traffic control approach of updating a train's movement authority based upon the amount of traffic involved.
Foreign Locomotive	a locomotive owned by one railroad when used by another.
Intelligent Railroad Systems	a general term applied to systems for railroads that use an array of sensors, computers, and digital communications to improve the safety and/or efficiency of railroad operations.
Intermodal	the movement of freight in containers across multiple transport modes.
Mathematical Planner	a set of mathematical algorithms that is used to optimize the objectives of traffic management selected by a railroad for its operation.
Movement Authority	the permission provided to a train crew to advance the train as to distance, speed, and/or time. In signaled territory, the movement authority is provided as an aspect (a configuration of lights) that indicates permission to proceed and speed restriction. In non-signaled territory, the authority is transmitted by the train dispatcher to the train crew.
Moving Block	the ultimate traffic control approach of continuously updating a train's movement authority.
Narrowbanding	a.k.a. refarming, a FCC Point & Order to split the frequencies in half in a portion of the VHF by 2013. An additional Point & Order was issued in March 2007 to note that the same channels would be split again at some point, but no date was provided.

Non-Signaled Territory	a method of train operation in which the primary authority is generated by a manual process(train sheet) or a computerized conflict checker. The transmission of the authority to the train crew is done by the train dispatcher. There are two types of dark territory. One in which there are no signals (most common). The second type, known as Absolute Manual Block, incorporates signals in the territory, but the signals only provide a secondary level of authority within the primary authority, and their aspects are not provided to the dispatcher.
Object Oriented	a software design approach that establishes a number of functional objects for the application being designed with a standard set of messages between the objects. For PTC an O/O on-board platform would permit the suppliers to choose which objects they which to supply without being required to provide the whole system.
Pole Line	the structure that runs parallel to a railroad's tracks upon which some combination of telephone, power, and code lines are carried.
Positive Train Control	a system that is used to prevent train crew errors. There are 4 core objectives of PTC. 1. prevent train to train accidents, 2. prevent trains from over-speeding, an 3. prevent trains from endangering work gangs. An overlay PTC system is one which does not affect the method of operation, meaning that it is not vital.
Proactive Management	using timely status data of resources to predict possible conflicts and then to have solutions provided to reduce the consequences of those conflicts, if not eliminate them all together.
Railinc's EMIS	Equipment Management Information System is an industry-available data base of parameters and repairs to rolling stock that is maintained by the AAR-owned Railinc entity.
R C L	Remote Control Locomotive: a wireless application that permits an individual on the ground to move a locomotive. This application is used for switching in yards. This should not be confused with pursuit of one-person crews which involves main line operations.
S C A D A	Supervisory Control and Data Acquisition: "a system that is placed on top of a real-time control system to control a process that is external to the SCADA system (i.e. a computer, by itself, is not a SCADA system even though it controls its own power consumption and cooling). This implies that the system is not critical to control the process in real time, as there is a separate or integrated real-time automated control system that can respond quickly enough to compensate for process changes within the time constants of the process. The process can be industrial, infrastructure or facility..." (Source: Wikipedia).
Traffic Management	the management of the traffic control process to meet a railroad's objectives for the movement of trains. This is the true purpose of the train *dispatcher*.
Traffic Control	the process that generates movement authorities that thereby is the *vitality* of rail operations. This is not what the dispatcher does directly, but is what s/he often initiates in the traffic management process.
Vitality	From a safety design perspective, vitality means that the device / system will fail safely, i.e., with no increase in risk. From a railroad operation standpoint, vitality refers to the functionality of the hardware and/or software that generates movement authorities that provides for the integrity of train movements.